Recent femtoscopic results from the STAR experiment

Adam Kisiel,
Ohio State University

for the STAR Collaboration

37TH INTERNATIONAL SYMPOSIUM ON MULTIPARTICLE DYNAMICS

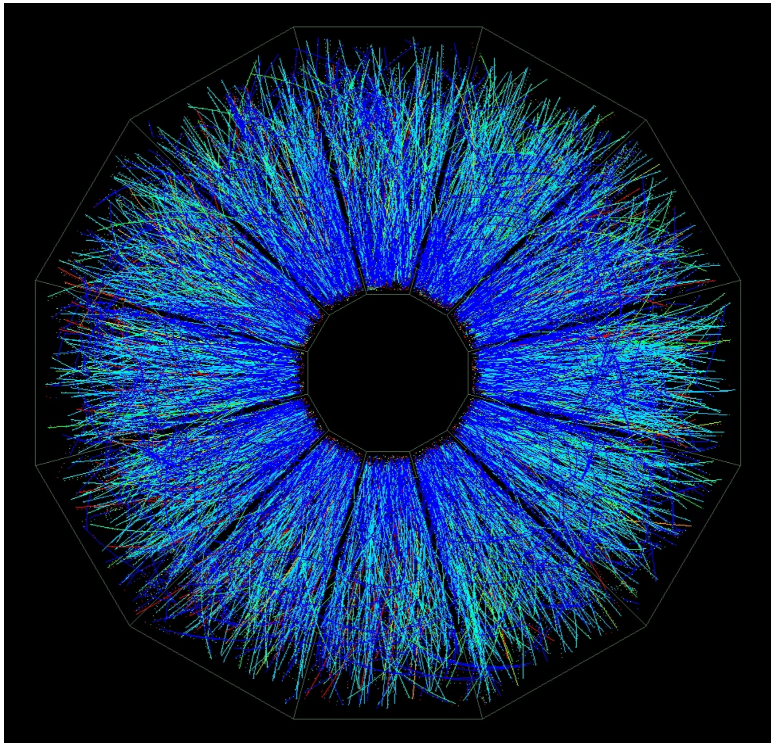
AUGUST 4 - 9, 2007
LAWRENCE BERKELEY NATIONAL LABORATORY
BERKELEY, CA

Outline

- Continuing systematic studies:
  - Results for other energies
  - Different colliding systems
  - Multiplicity scaling
  - Volume scaling and constant mean free path at freeze-out
  - k_T dependencies
  - Correlations with other pair types
- Expanding the field:
  - Studying two-particle interaction potentials
  - Non-identical particle correlations and the asymmetry measurement
  - Correlations with exotic particles
  - Correlations in small multiplicity systems

The STAR Experiment

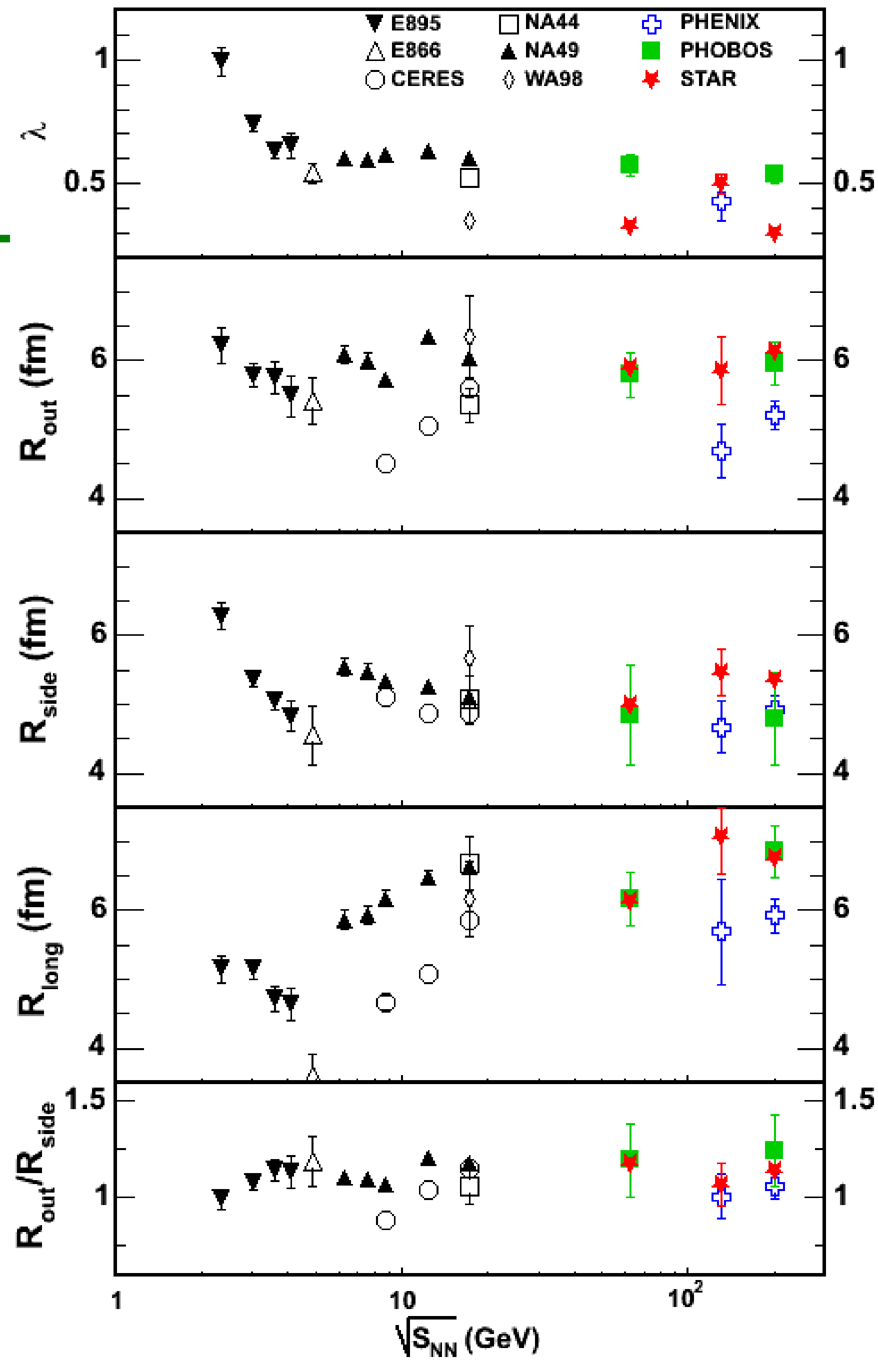
- Available datasets:
  AuAu: 200 AGeV, 62 AGeV
  CuCu: 200 AGeV, 62 AGeV
  pp: 200 GeV
  dAu: 200 AGeV



- 52 institutions from 12 countries
- Large acceptance TPC detector: $-1<y<1$ and 2π in azimuthal angle
- Pions, kaons and protons identified via dE/dx for p_T $0.12 - 1.2\ GeV/c$
- $V0$'s identified by their decay topology

HBT excitation function

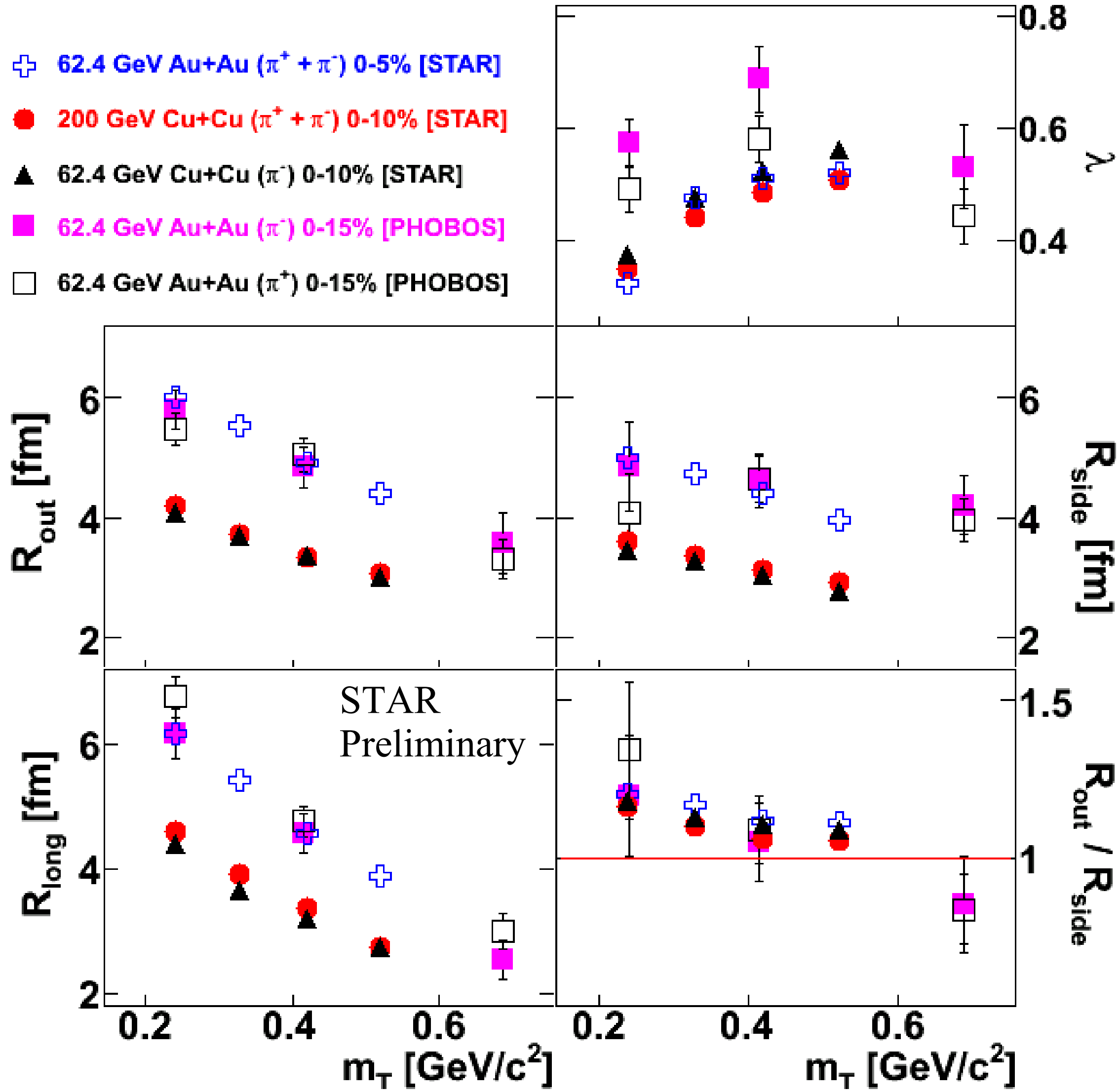
- No dramatic change in radii with energy of the collision observed in the RHIC energy range
  - Not consistent with "large-lifetime" scenario expected in the 1st order phase transition
  - How is it possible that 10x increase of energy does not change the size?



$$R(\sqrt{S_{NN}}, m_T, b, N_{part}, A, B, PID)$$

CuCu and 62 GeV results

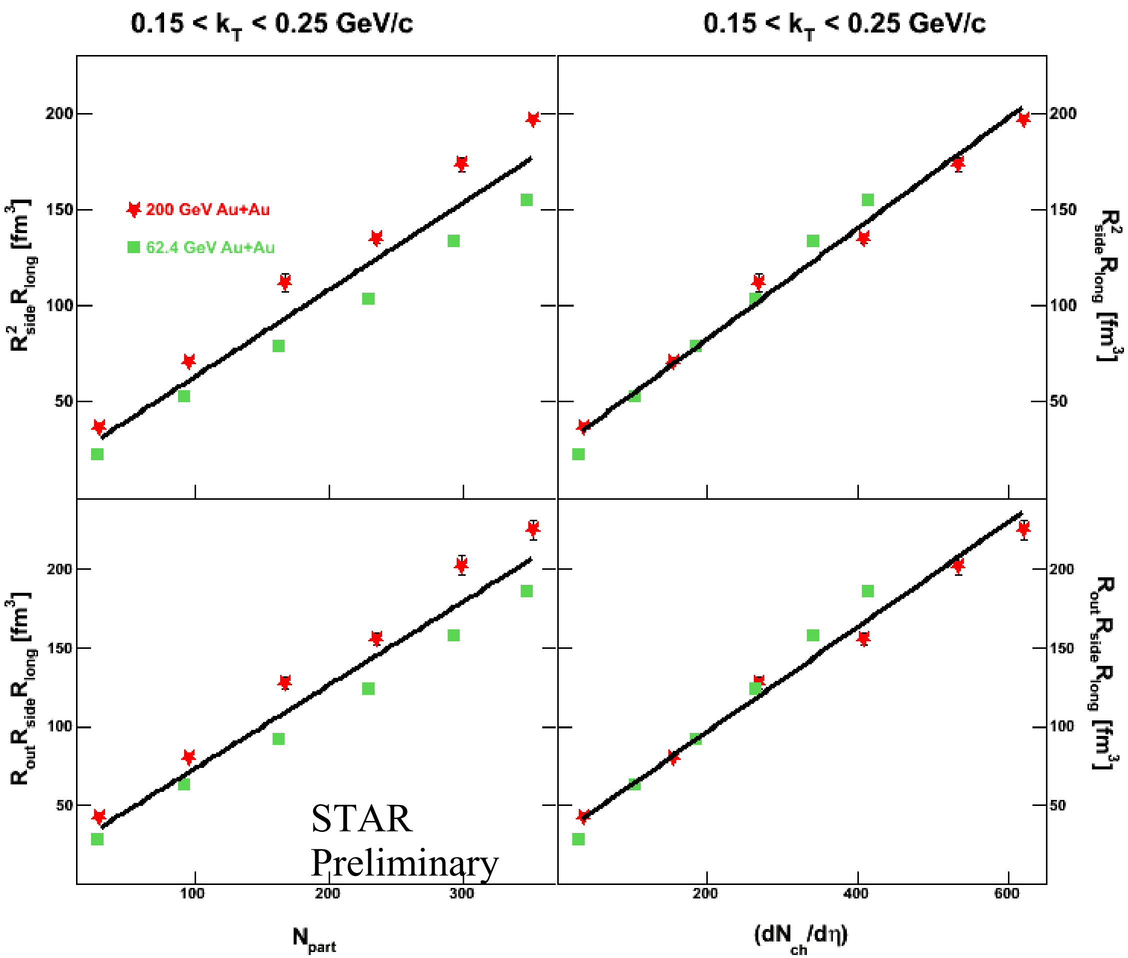
- Extending systematic study of pion femtoscopy
- Different collision energy and system type show patters seen previously in AuAu.
- Both show strong radial flows and expected trend in radii vs. centrality and k_T.



Debasish Das

Searching for scaling laws

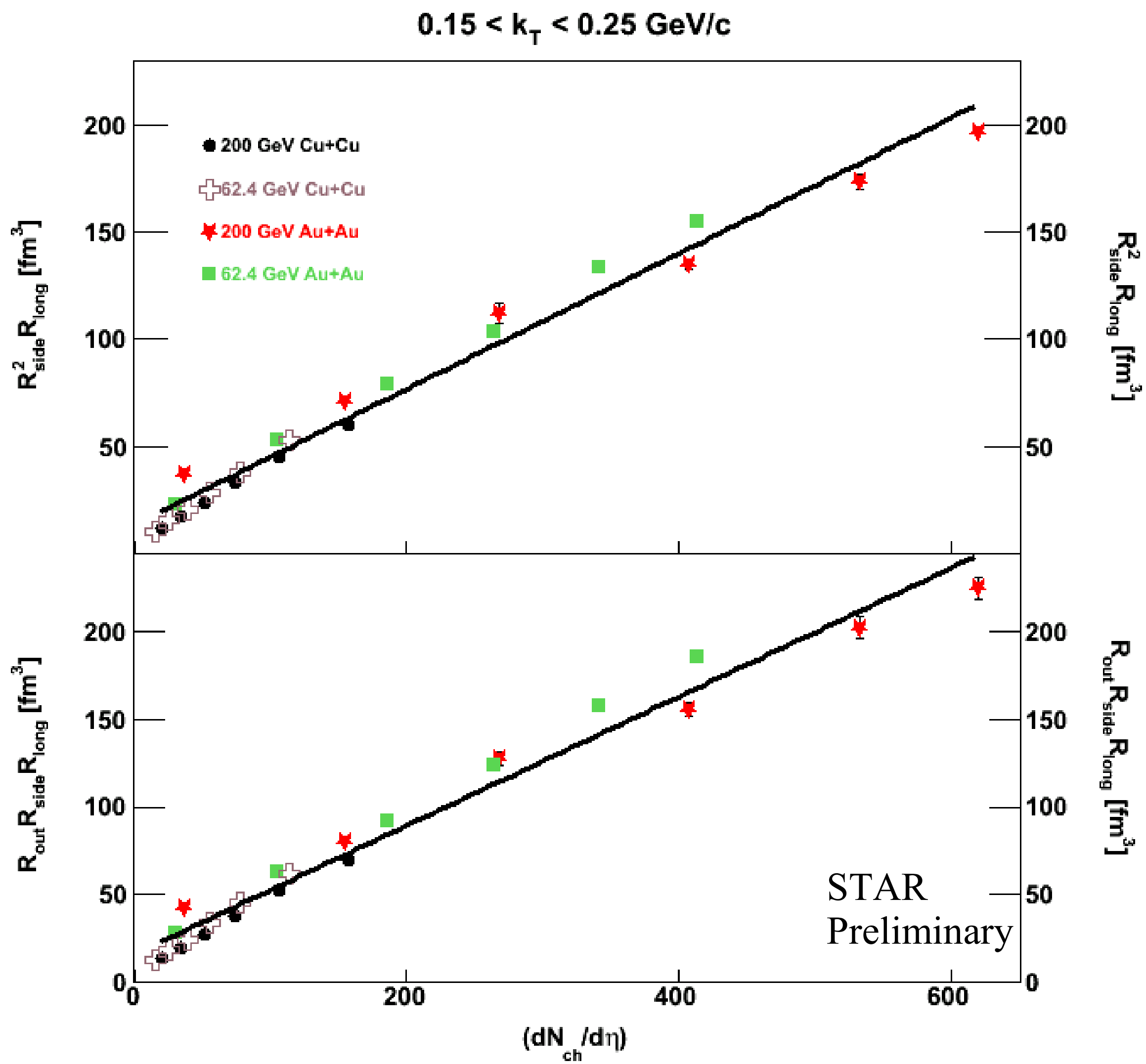
- Two scaling laws have been propsed for femtoscopic radii
- Our study shows that observed multiplicity is a better scaling variable than N_{part} – femtoscopy is final state (entropy) dominated



Debasish Das

Freeze-out at constant mean free path

- We plot all the measured systems vs. the scaling variable showing universality of the scaling
- The results suggests constant mean free path as a freeze-out criteria for pions



Beyond HBT radii - source imaging

- Task imaging is to determine the source *S(r)* from data with errors *C(q)* by inverting the Koonin-Pratt equation

$$R(q)=C(q)-1=4\pi\int r^2\left(|\Phi_q^{(-)}(r)|^2-1\right)S(r)\,dr$$
$$R(q)=4\pi\int r^2 K(q,r)S(r)\,dr$$

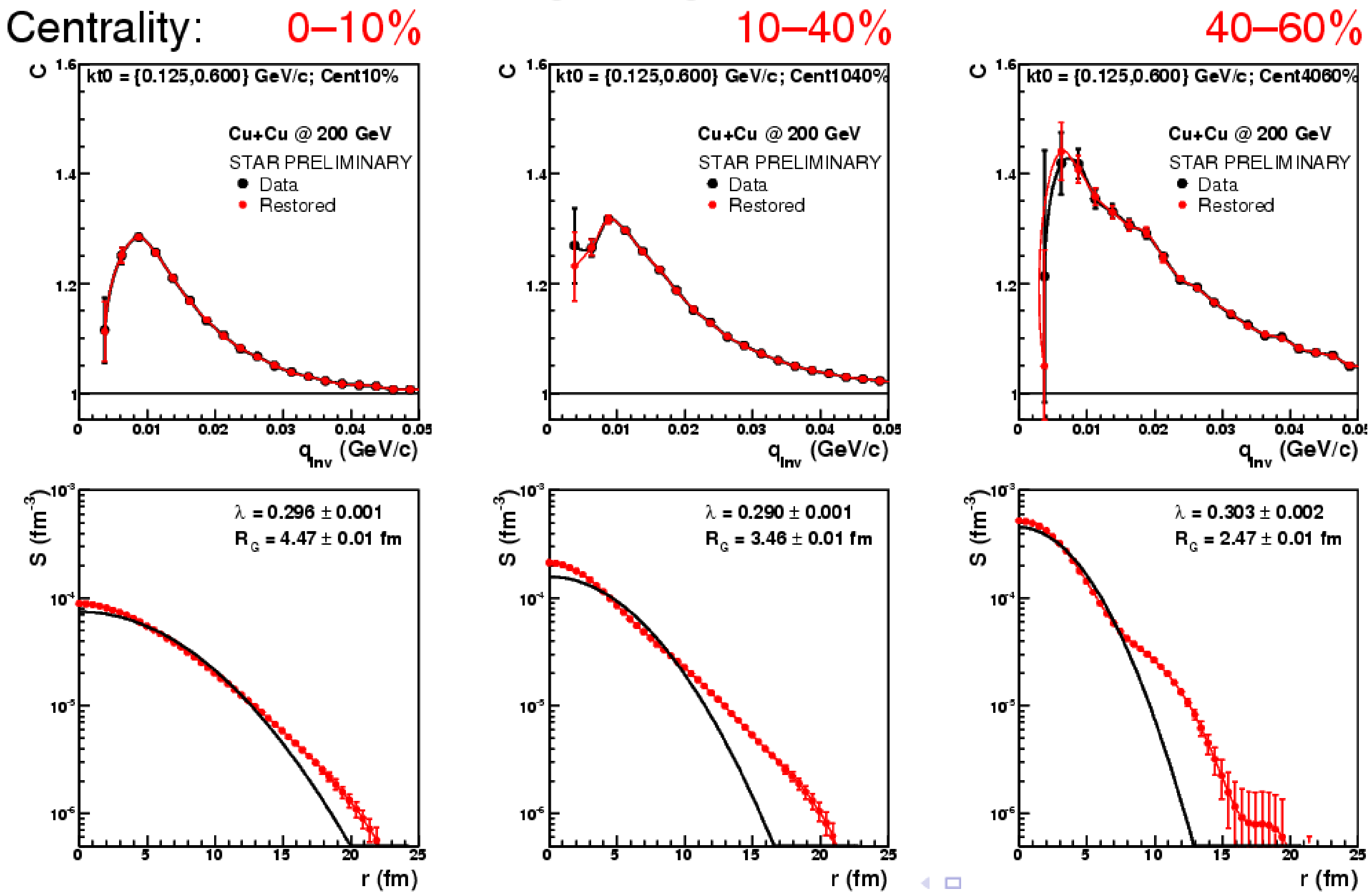
requires the inversion of the interaction kernel *K(q,r)*

- Inversion procedure in matrix form, expansion in B-spline basis:

$$S(r)=\sum_j S_j B_j(r) \qquad R_i^{Th}=\sum_j K_{ij}S_j \qquad K_{ij}=4\pi\int r^2 K(q,r)B_j(r)\,dr$$

vary S_j to minimize $\chi^2=\frac{\sum_i (R_i-R_i^{Th})^2}{\Delta^2 R_i}$

Imaging results

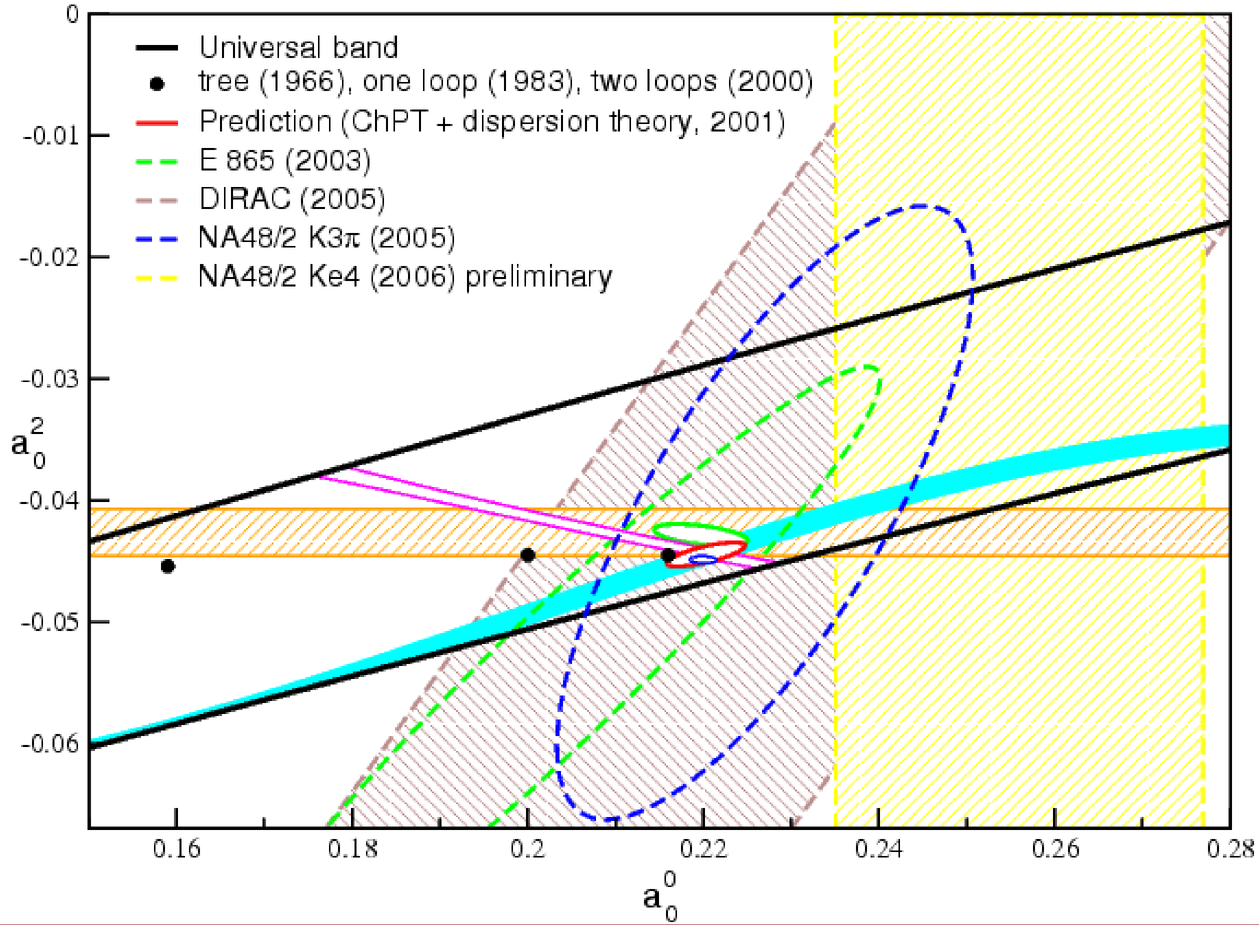


- Imaging resolves non-gaussian long-range tail structures in the pion emission source

Experimental situation for a_0^0, a_0^2

- DIRAC ($A_{2\pi} : \pi^+\pi^- \to \pi^0\pi^0$) $\Longrightarrow 1/\tau_{A2\pi} \sim (a_0^0 - a_0^2)^2$
- NA48/2 ($K_{3\pi} : K^\pm \to \pi^0\pi^0\pi^\pm$) $\Longrightarrow (a_0^0 - a_0^2)$
- E865, NA48/2 ($K_{e4} : K^\pm \to \pi^+\pi^- e^\pm \nu$) $\Longrightarrow a_0^0$
- TRIUMF ($\pi^+ p \to \pi^+\pi^+ n$) $\Longrightarrow a_0^2$

H. Leutwyler, Moriond 2007



ChPT prediction

(Colangelo, Gasser, Leutwyler, hep-ph/0007112)

$$a_0^0 = 0.220 \pm 0.005\ [m_\pi^{-1}]$$

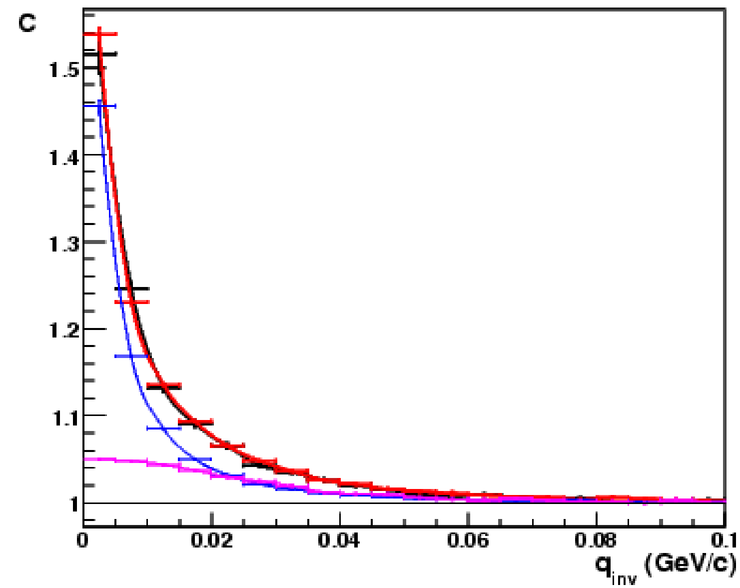
$$a_0^2 = -0.0444 \pm 0.0010\ [m_\pi^{-1}]$$

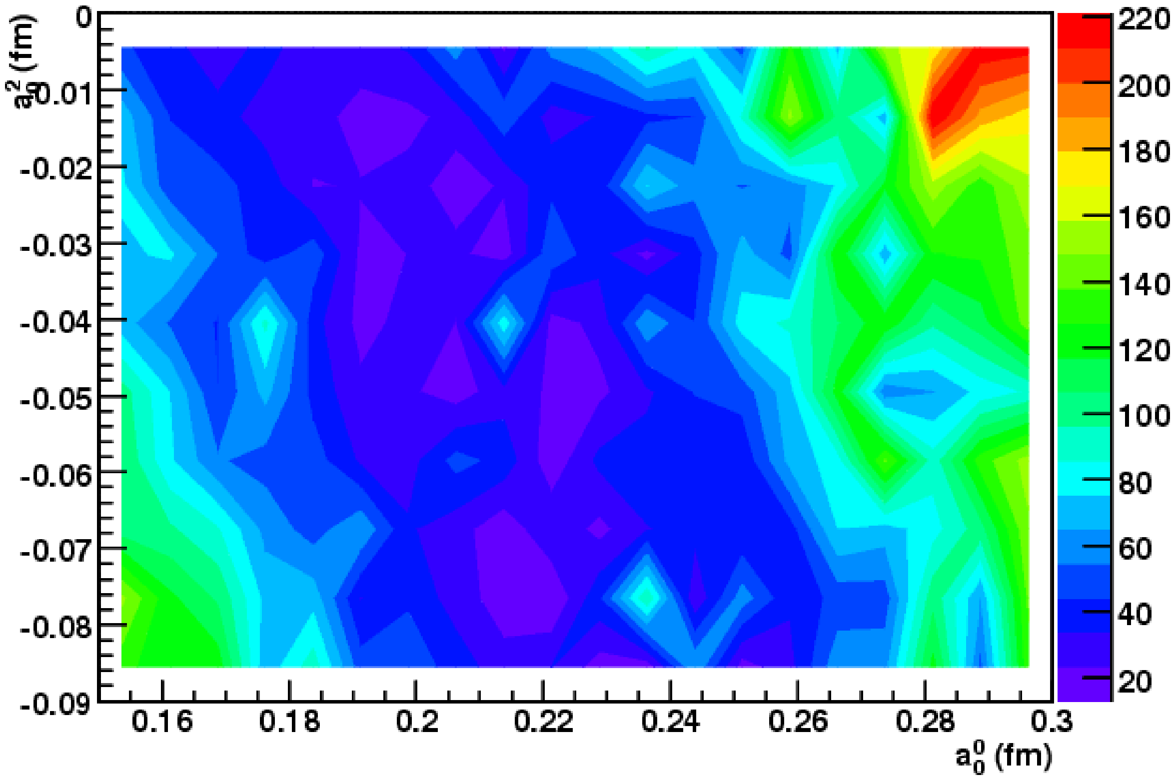
$$a_0^0 - a_0^2 = -0.265 \pm 0.004\ [m_\pi^{-1}]$$

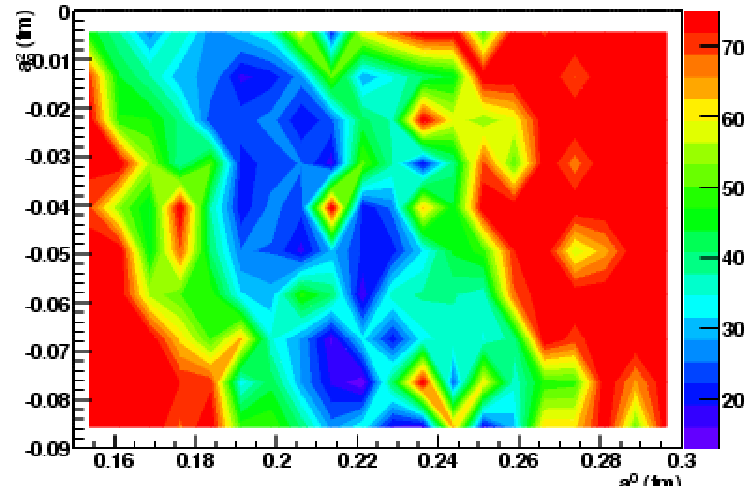
Scattering length from STAR

k_T: 0.125–0.250 GeV/c

- PRELIMINARY results
- Coulomb + Strong FSI fit to data $\longrightarrow$
- vary a_0^0, a_0^2 $\Longrightarrow$ χ^2 map

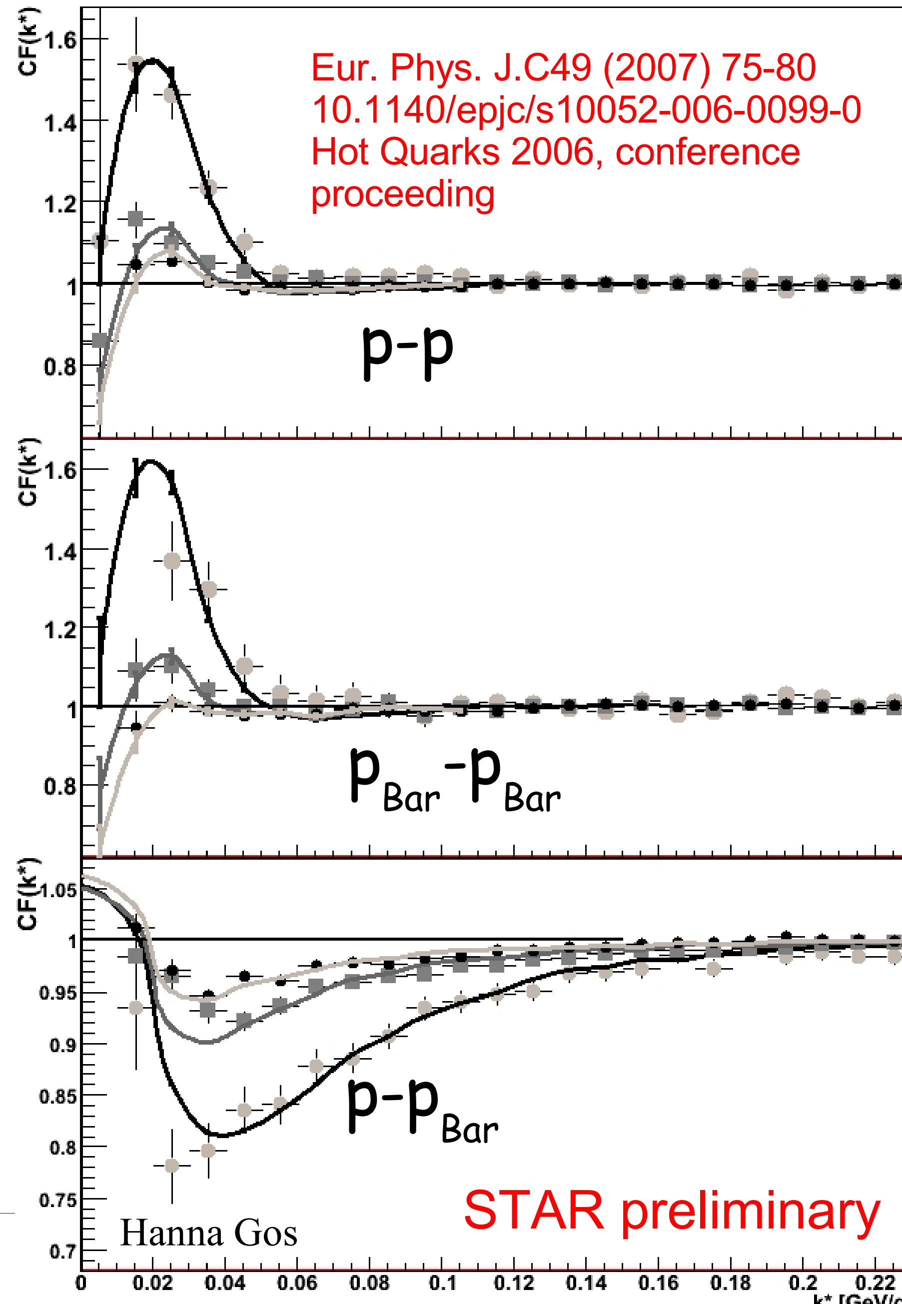






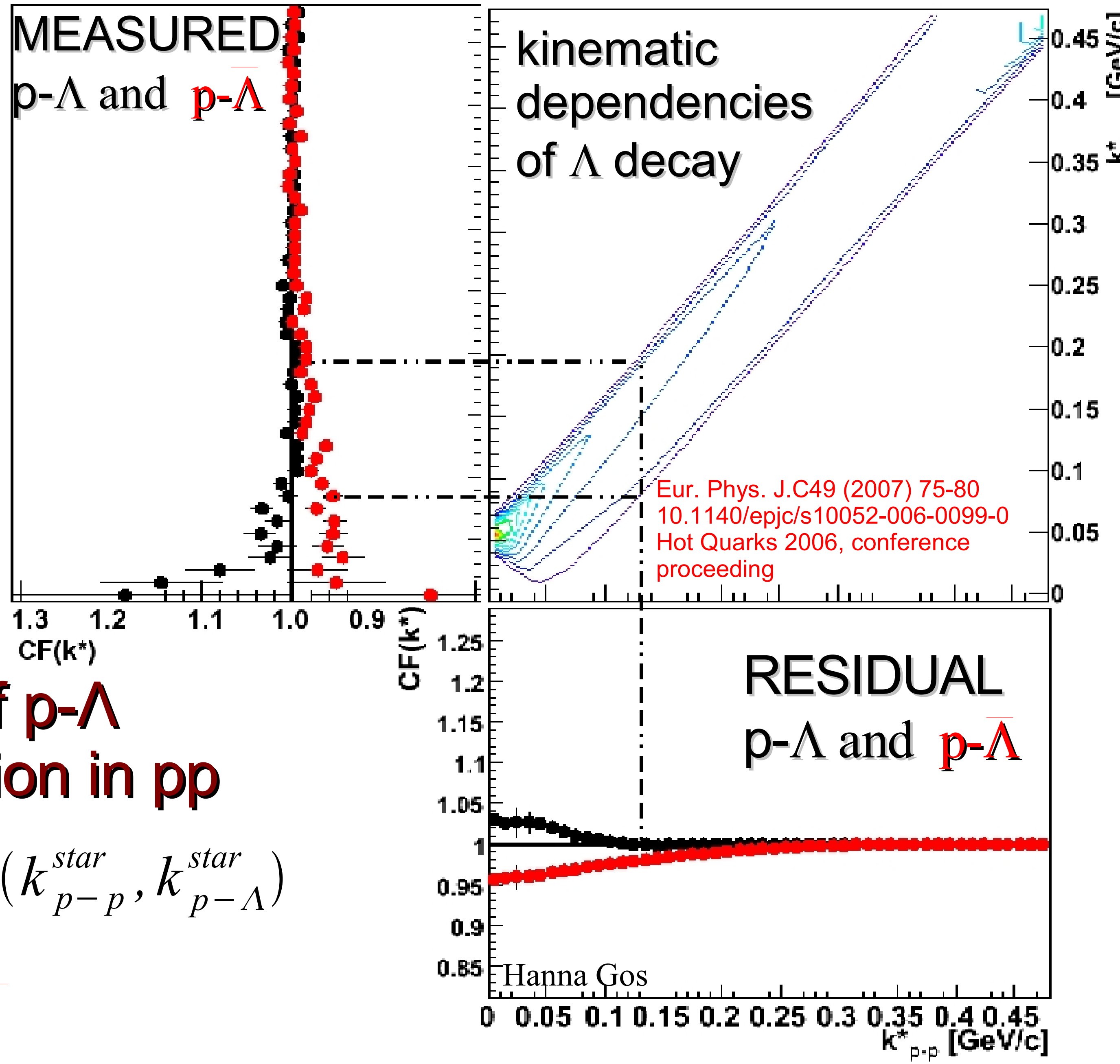
Correlations with (anti-)baryons

- We want to test the scaling laws for particles with different properties (larger mass, baryons)
- The proton-antiproton correlation functions have been measured for the first time
- Simple purity correction is not sufficient for the baryon systems



Residual correlations in pp system

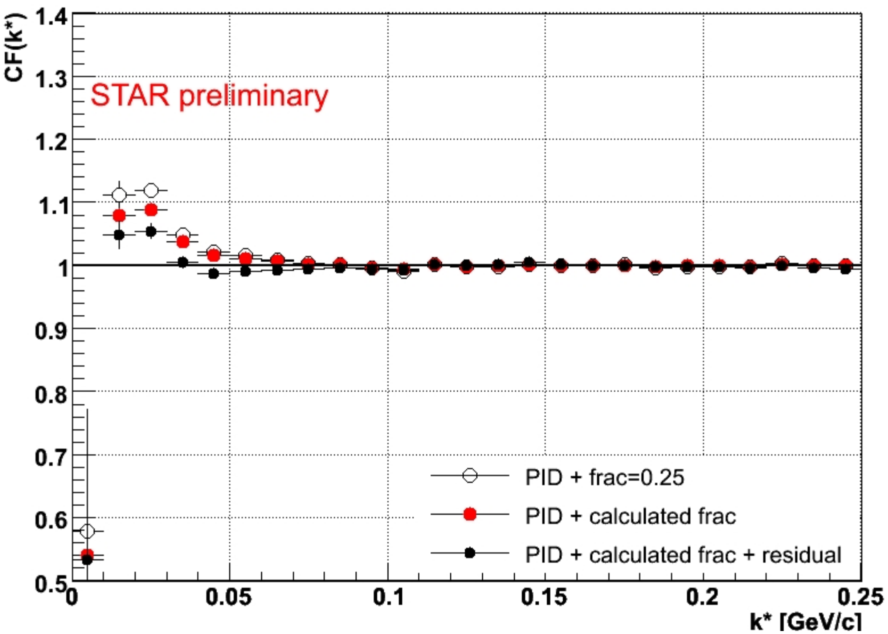
- Residual correlation of pΛ carries over to proton-(anti-)proton correlation

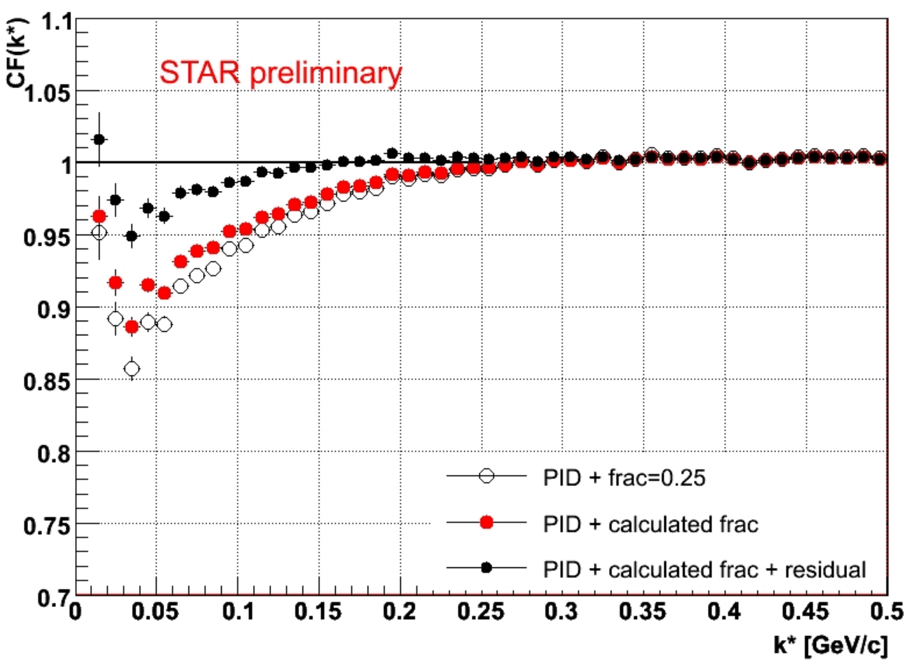


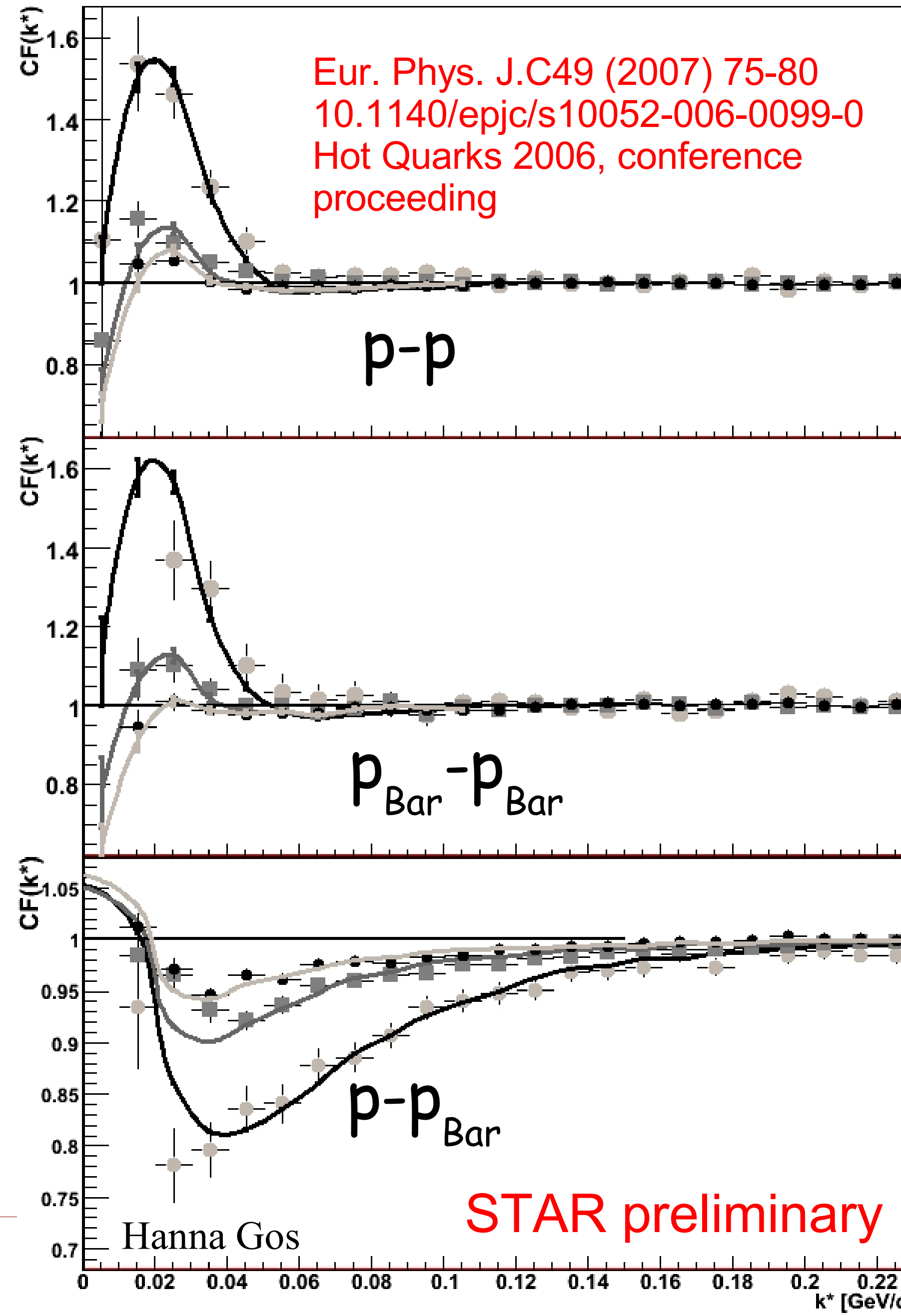
The estimation of p-Λ residual correlation in pp

$$\sum_{k^{star}_{p-\Lambda}} CF^{meas}_{p-\Lambda}(k^{star}_{p-\Lambda})\, W(k^{star}_{p-p}, k^{star}_{p-\Lambda})$$

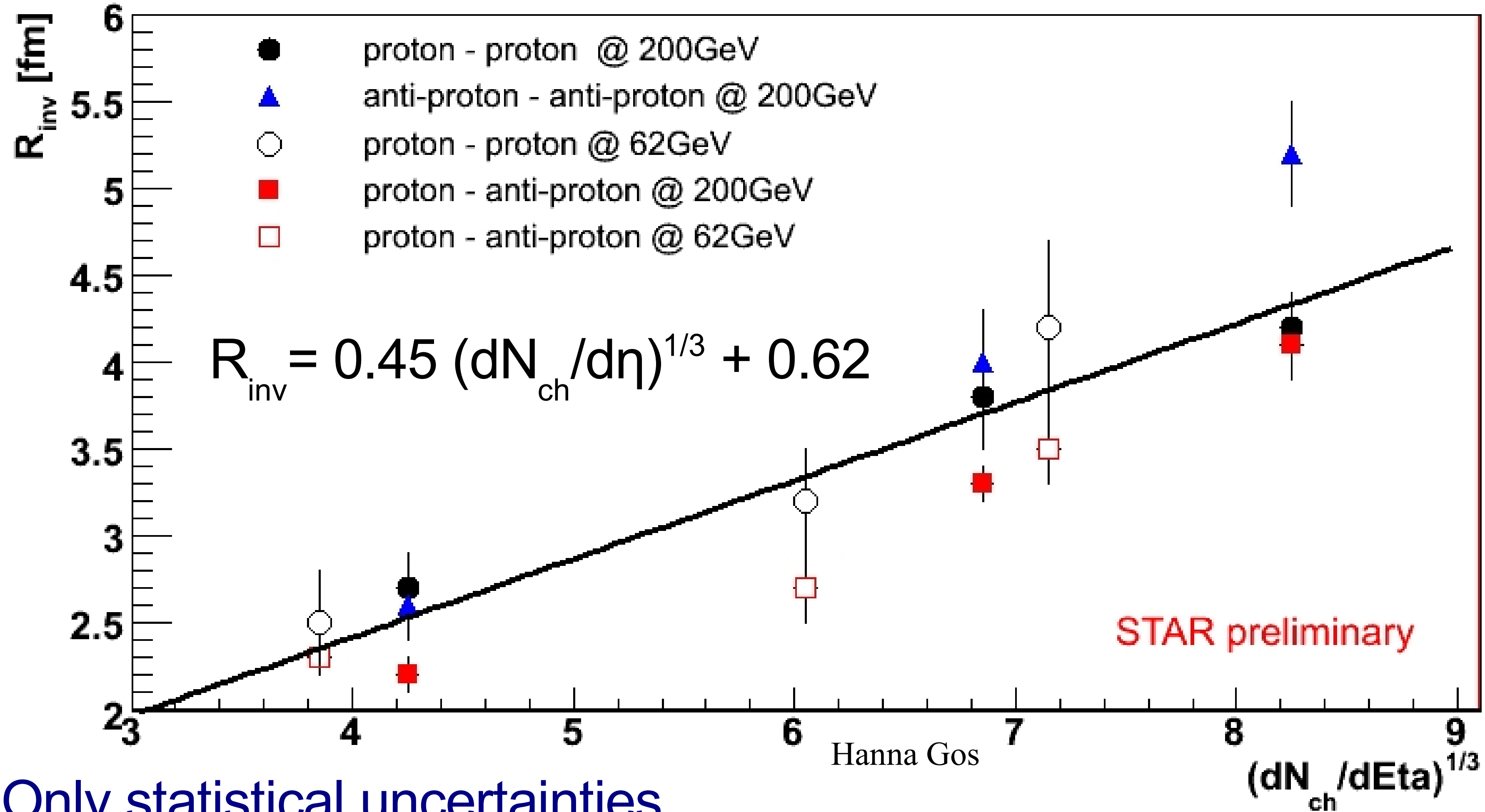
Results after residual corrections







Multiplicity scaling for baryons

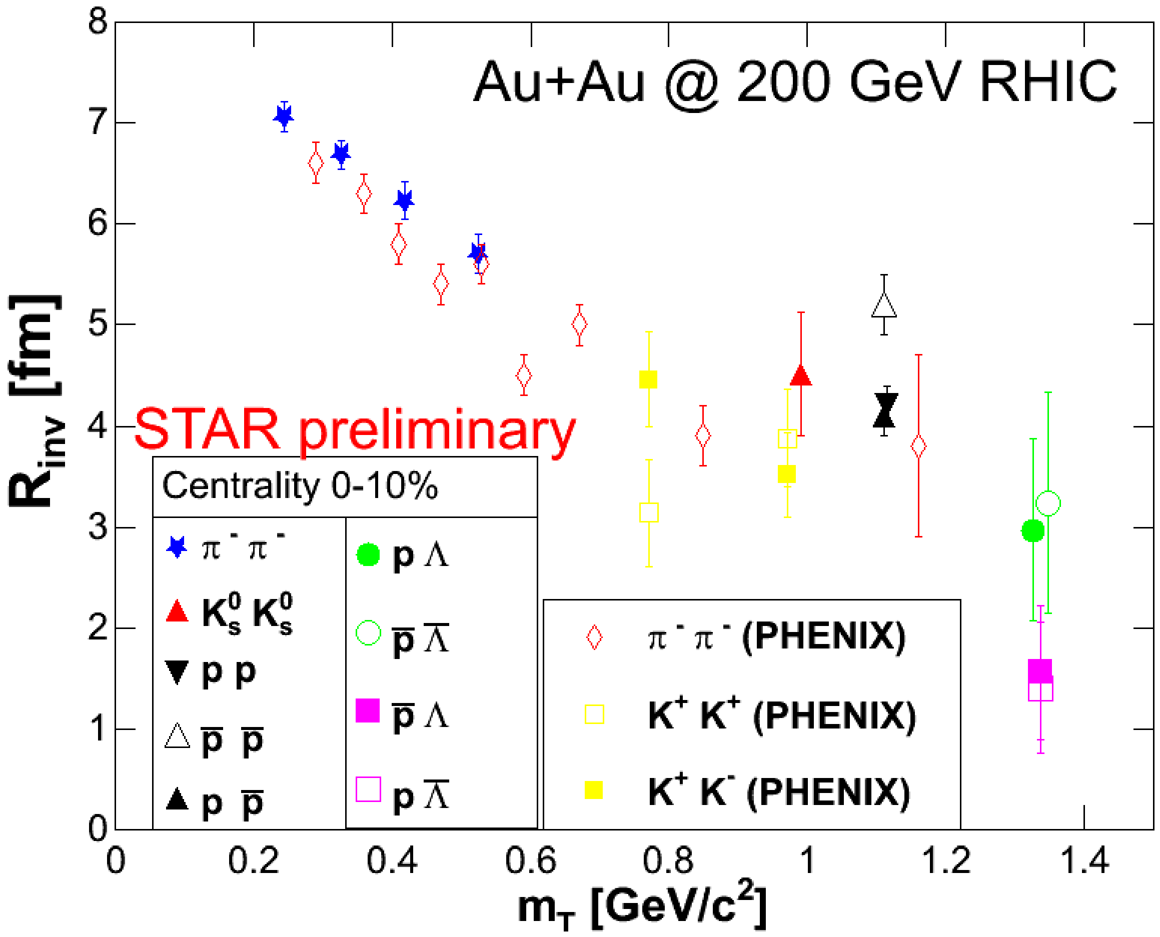


Only statistical uncertainties
Systematic error ~0.5 fm not shown

Eur. Phys. J.C49 (2007) 75-80
10.1140/epjc/s10052-006-0099-0
Hot Quarks 2006, conference proceeding

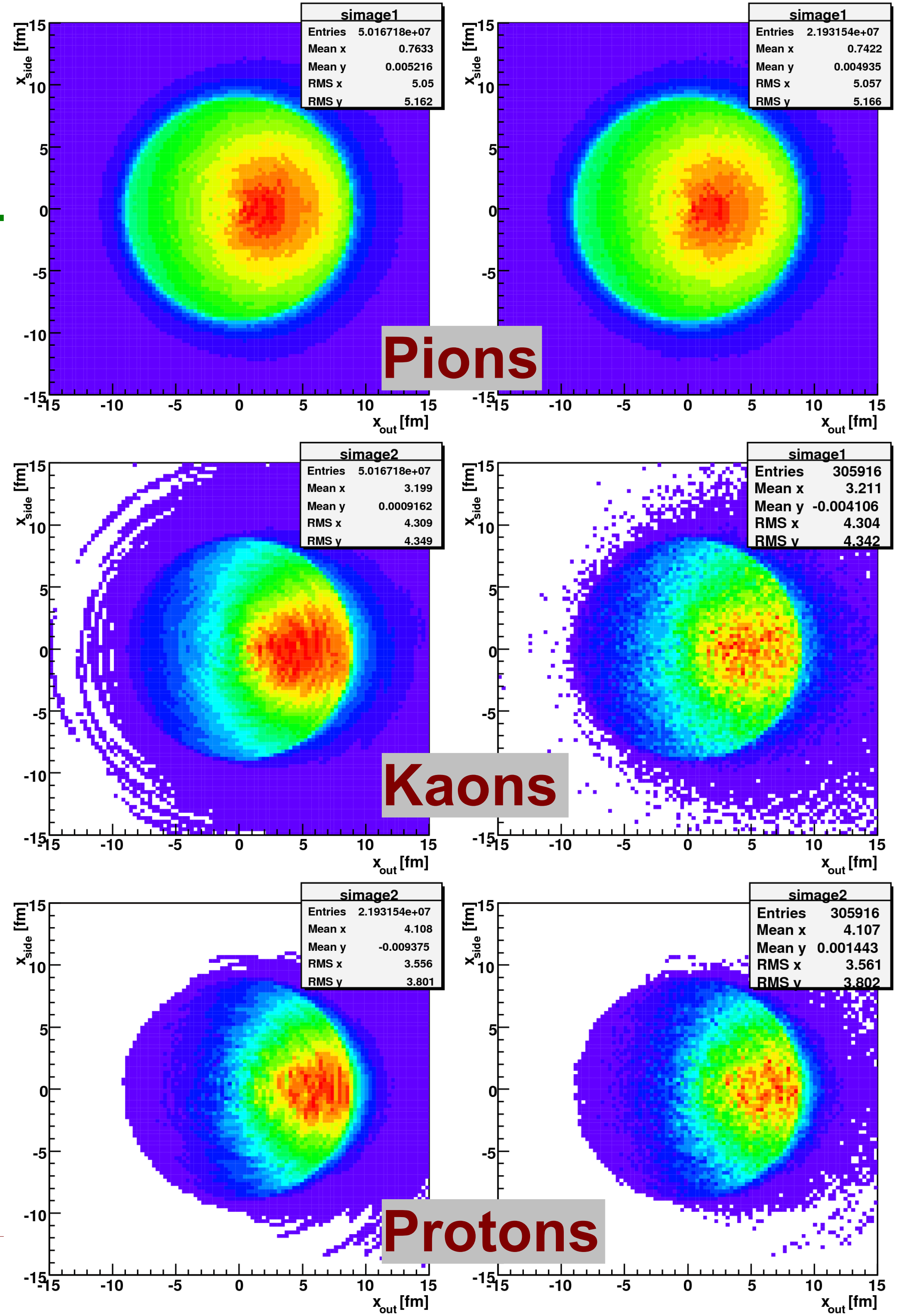
Global m_T dependence

- All particle species follow the global m_t systematics – building a consistent picture of collective dynamics



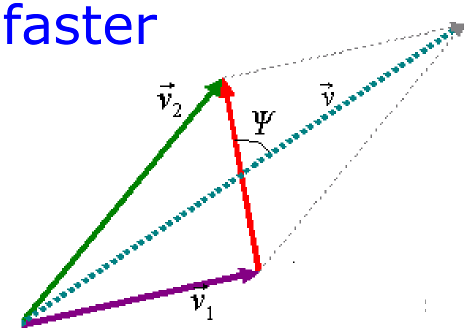
Emission points and flow

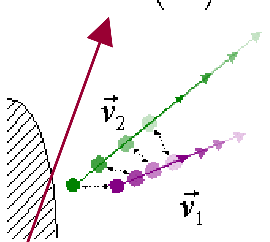
- The effects of radial flow are two-fold:
  - The average emission points in *out* direction are different for pions, kaons and protons – spatial shift between particles of different masses
  - The average size of emission region gets smaller with particle mass – m_T scaling of radii

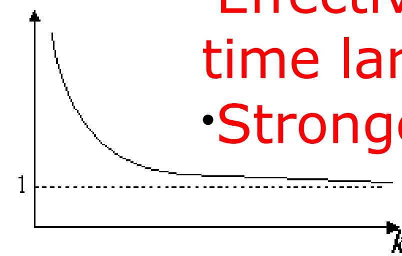


The asymmetry analysis

Heavier particle faster



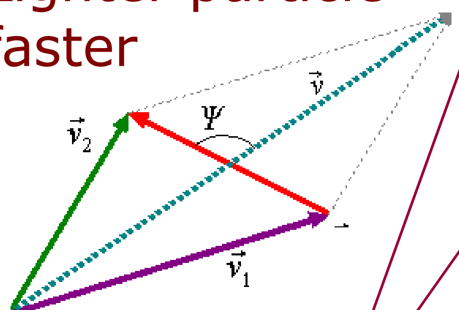


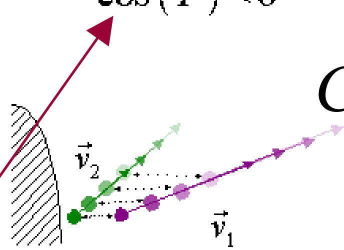


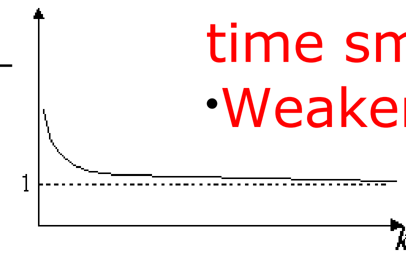
Catching up

- Effective interaction time larger
- Stronger correlation

Lighter particle faster

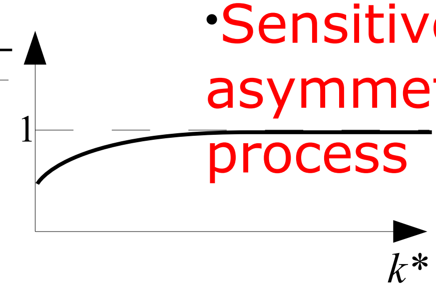






Moving away

- Effective Interaction time smaller
- Weaker correlation



"Double" ratio

- Sensitive to the space-time asymmetry in the emission process

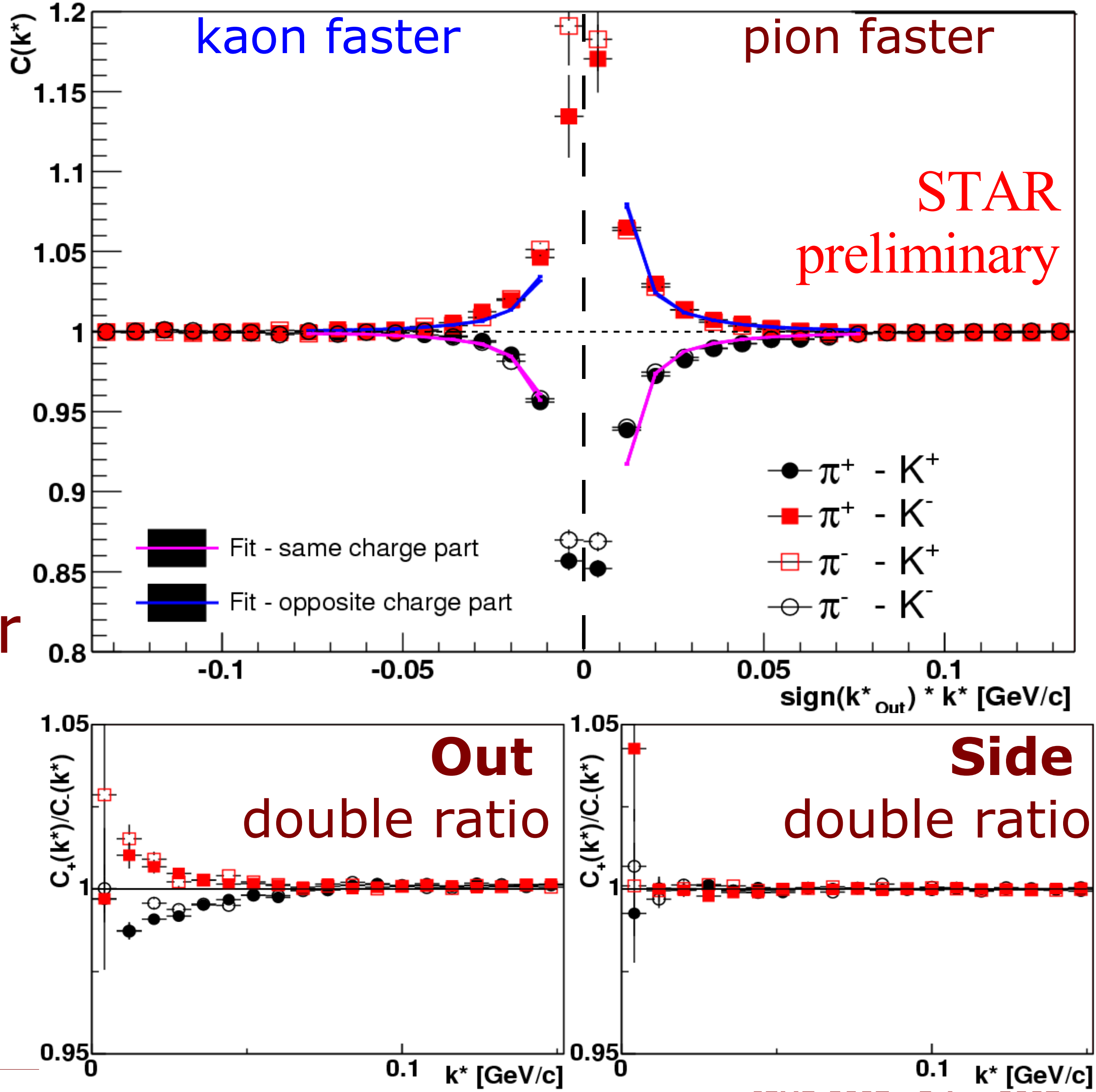
Kinematics selection along some direction

e.g. k_{Out}, k_{Side}, cos(v,k)

R.Lednicky, V. L.Lyuboshitz, B.Erazmus, D.Nouais, Phys.Lett. B373 (1996) 30.

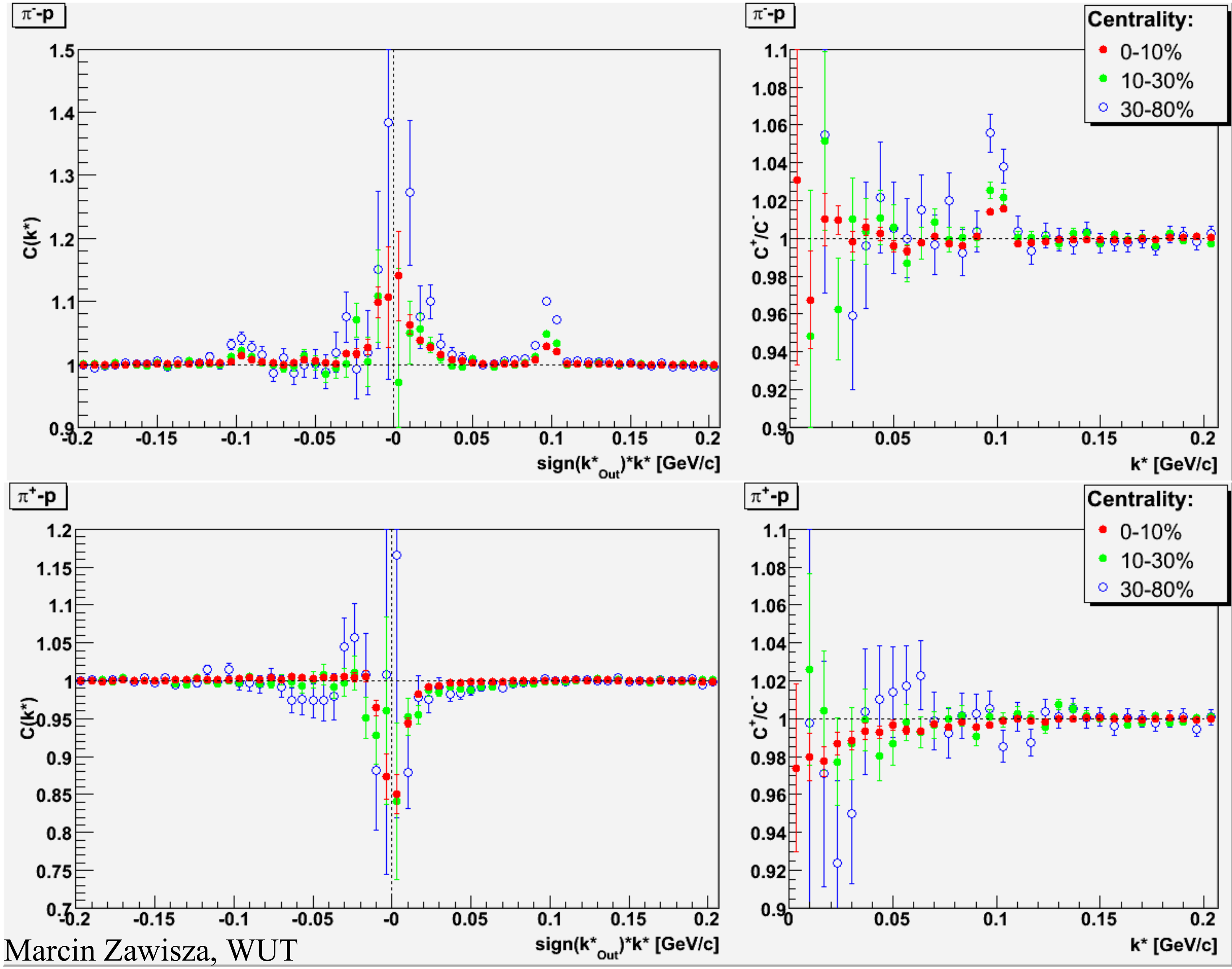
Pion-Kaon asymmetry

- Good agreement for same-charge combinations
- Clear emission asymmetry signal
- Systematic error under study – influenced by purity and fits to all CFs separately



Pion-proton asymmetry

- Asymmetry is observed for pion-proton systems, for all centralities, consistent with the radial flow hypothesis

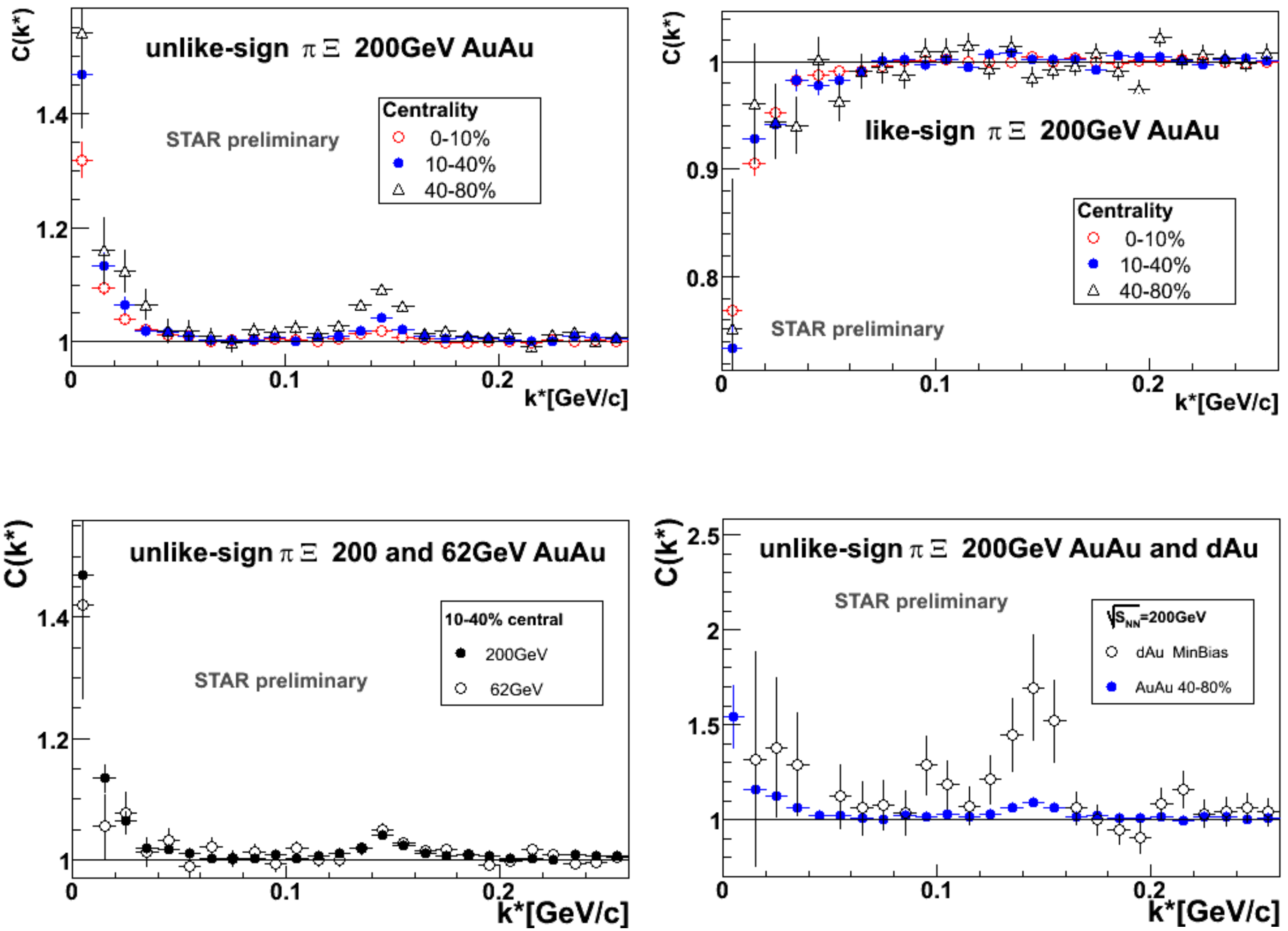


Why π–Ξ correlations?

- **Why is Ξ elliptic flow comparable to other hadrons? Is that all suggesting early partonic collectivity?**
- **Ξ (as well as other multi strange baryons) may have thermal freeze-out behaviour differing from the other hadrons: early decoupling?**
- **What is the production mechanism of Ξ*(1530) resonance?**

Femtoscopy with exotic systems

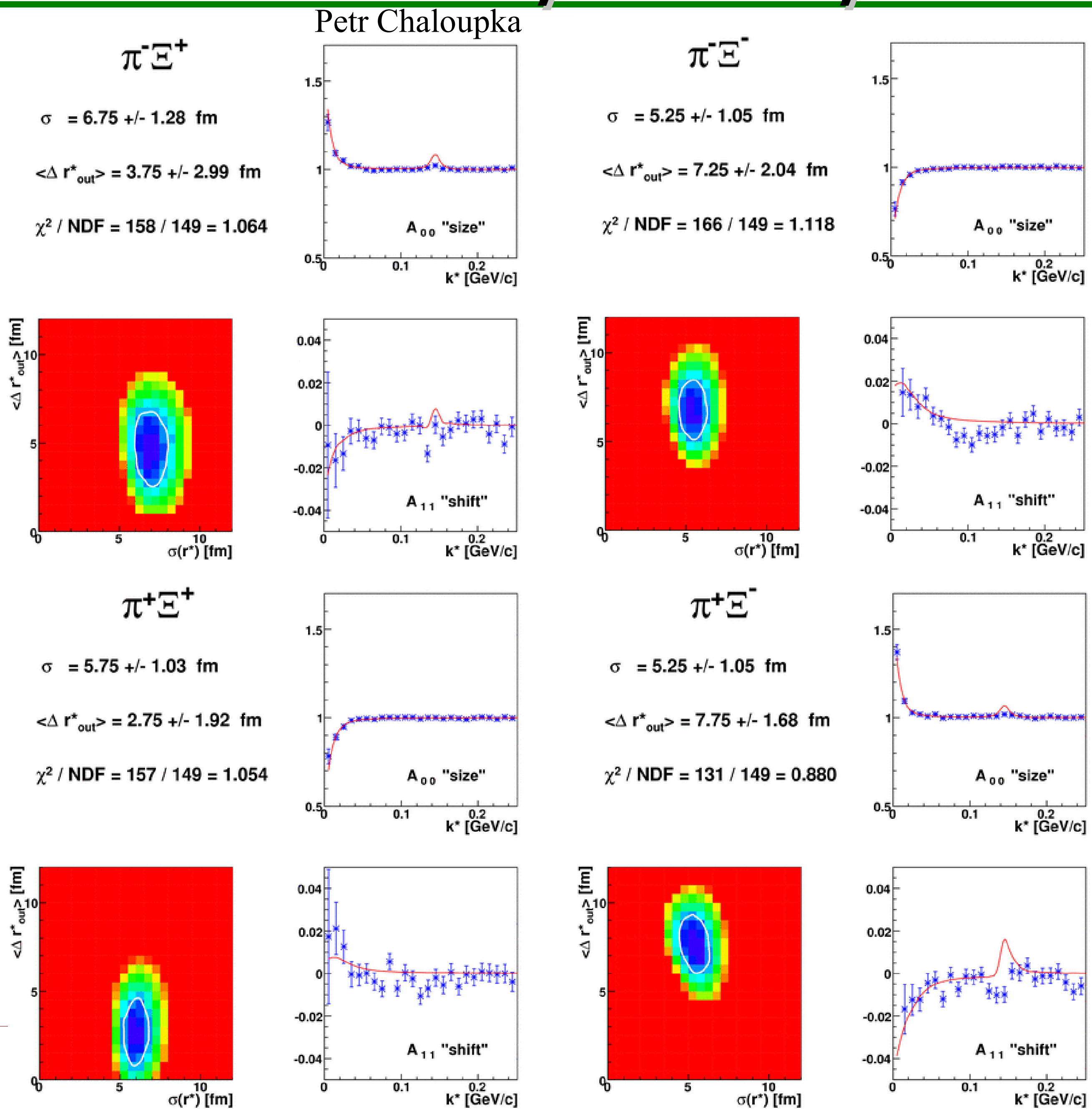
- Robust signal is seen for pion-Xi correlations in both like-sign and opposite-sign systems.
- Significant Xi* peak is observed as well as the correlation coming from Coulomb



Petr Chaloupka

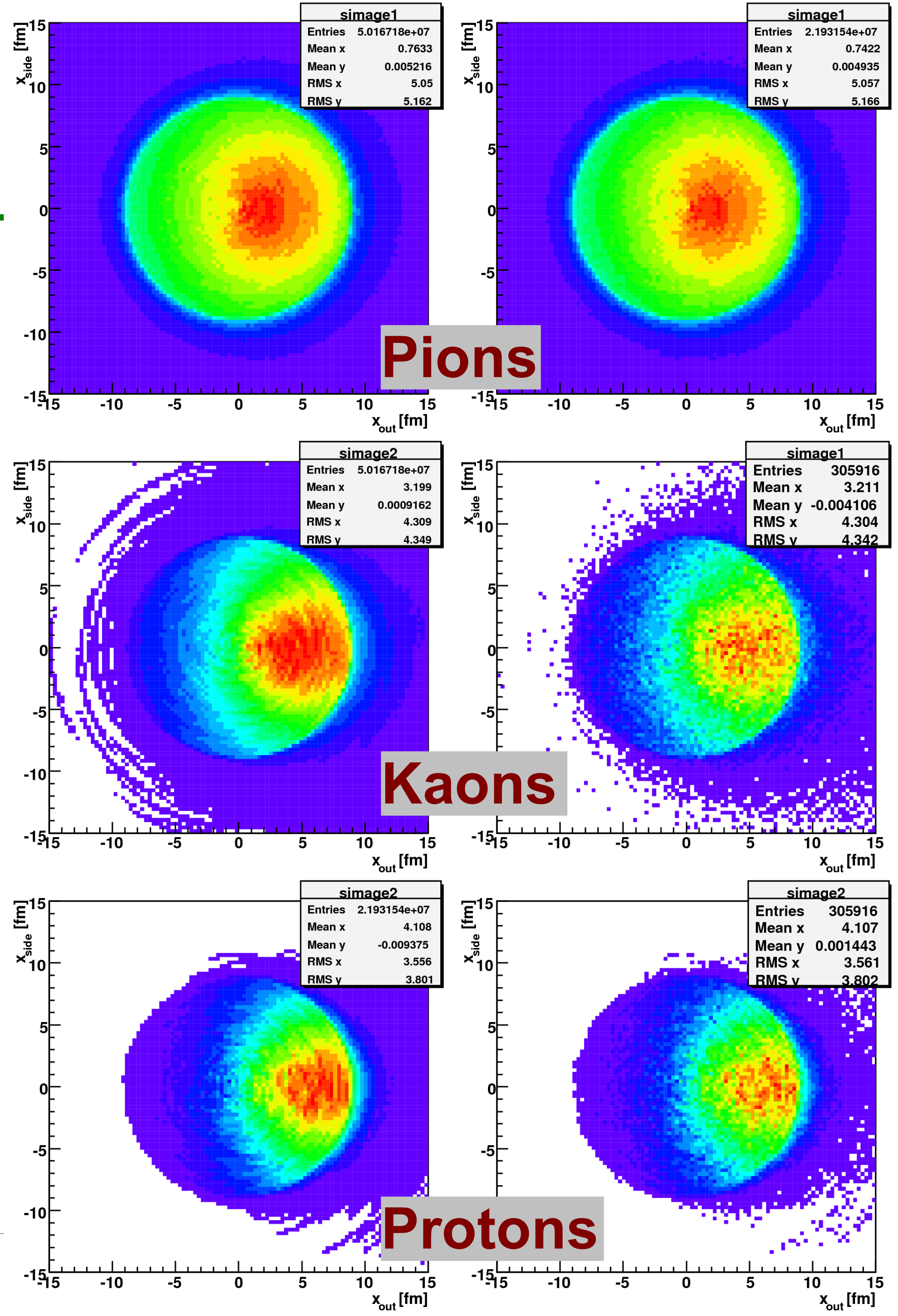
Fitting the emission asymmetry

- Emission asymmetry is observer for all pair types confirming strong radial flow of Xi
- Size suggests early Xi freeze-out
- Asymmetry seems to divide pairs into baryon and anti-baryon groups



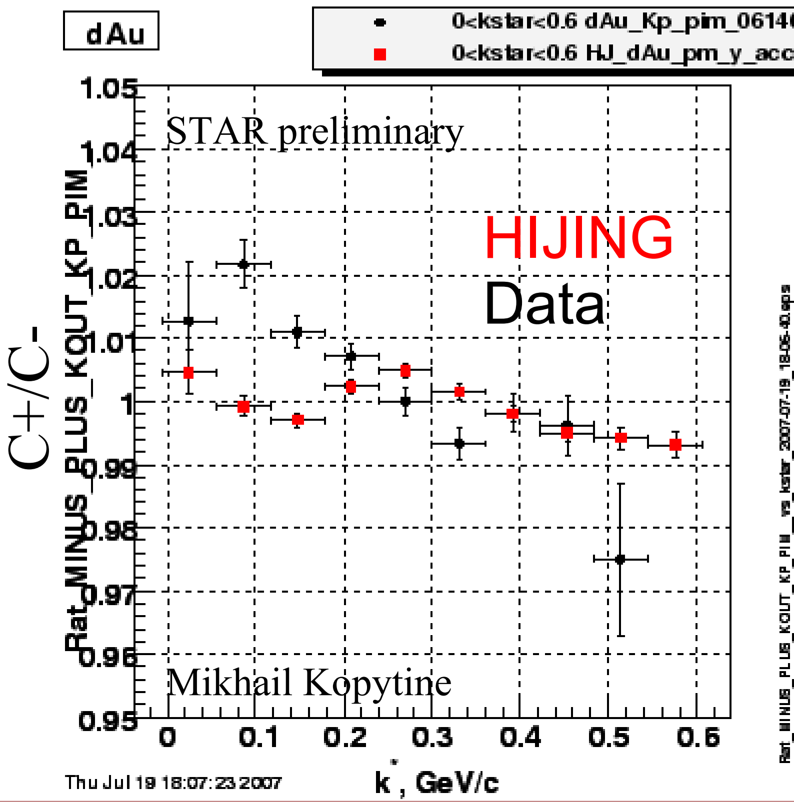
Emission points and flow

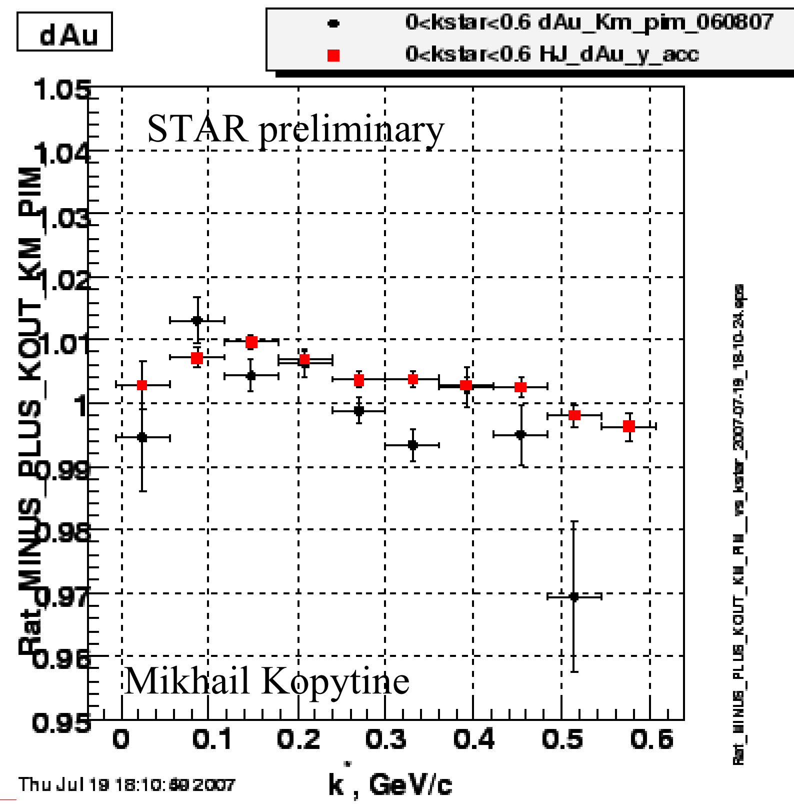
- The effects of radial flow are two-fold:
  - The average emission points in *out* direction are different for pions, kaons and protons – spatial shift between particles of different masses
  - The average size of emission region gets smaller with particle mass – m_T scaling of radii



Asymmetry in dAu

- Long-range structure observed – reproduced by HIJING simulations
- Femtoscopic asymmetry signal seems to remain at low k*





Summary

- STAR is continuing its femtoscopic program both by pursuing well-established analyses for available energies and colliding types as well as by trying out new techniques and challenging measurements
- Traditional pion femtoscopy provides a consistent picture of collision geometry at RHIC
- An imaging techinque promises to provide a detailed information about emission function
- Long-range baseline study has been performed for low-multiplicity collisions
- Asymmetry measurements provide unique information about space-momentum structure of the emission